EXECUTIVE SUMMARY

This report provides a detailed characterization of the ground motions that might affect Jackson Lake Dam due to a large earthquake on the Teton fault. The Teton fault is an active normal fault capable of producing **M** 7+ earthquakes. The surface trace of the fault is located 12 km (7 mi) west of Jackson Lake Dam. The fault plane dips to the east, likely extending to a position below the dam. This report is based on regional seismic monitoring data, empirical site response measurements, results of previous geologic investigations, and ground motion modelling.

This report examines ground motions from the Teton fault only. While there are other sources of earthquakes in the region, previous probabilistic seismic hazard analyses by Reclamation indicate that the Teton fault is the controlling seismic source based on proximity, activity rates, and maximum earthquake magnitudes. At some locations on the dam which are more susceptible to liquefaction, ground motions from additional sources may be significant. The emphasis in the current ground motion analyses is therefore to characterize potential Teton fault earthquakes, and to investigate the effects of geologic structure on seismic wave propagation and site response. This report provides design ground motions that are intended to be used as input for engineering analyses of the dam.

Teton Fault Characterization

Scarps formed by multiple latest Quaternary surface-faulting events mark the 60-km (37-mi) long trace of the Teton fault. Maximum slip rates appear to be in the range of 2 to 5 mm/yr along sections of the fault closest to the dam. Limitations in available geomorphic data result in a factor of 2 uncertainty in these slip rate estimates, as well as uncertainty in fault segmentation models. Several alternative rupture models are therefore considered, which incorporate a range of possible scenarios. From among these models, recurrence intervals for a large (**M** ~7) surface-rupturing earthquake on the Teton fault range from about 700 years to about 2000 years, with a weighted mean of about 1180 years.

The assumed dip of the Teton fault has a substantial effect on the modeled ground motions at Jackson Lake Dam. Lower fault dips result in stronger radiation of seismic energy, greater excitation of a low-velocity crustal basin below the dam, and potentially larger seismic moment

release. No direct data is available to constrain the fault dip. Recent analyses and compilations of coseismic rupture from historical earthquakes on other normal faults suggest a preference for dips near 45°, and a range of 30° to 60°. Seismic network data indicated that few earthquakes are located on (or near) the possible downdip projections of the Teton fault. Earthquakes located east of the surface trace of the Teton fault, however, have east-dipping nodal planes that dip from 25° to 60°. While there are too few recorded earthquakes located near the Teton fault to provide a strong constraint on fault dip, the spatial distribution of earthquakes is consistent with dips of less than 50°. Focal depths from well-located earthquakes are less than 14 km (9 mi), and extend to a maximum depth of about 17 km (10 mi), providing a basis to assign maximum faulting depths for ground motion modeling.

Focal mechanisms from 773 local earthquakes indicate that the contemporary state of stress would result in primarily normal-slip for the central and northern sections of the Teton fault, and oblique left-lateral normal slip on the southern section of the Teton fault. The focal mechanism data support using a dominantly normal-slip rake to simulate ground motions associated with rupture of the central and northern segments of the Teton fault.

Effects of Geologic Structure

The geologic structure of the Jackson Lake Dam area has a large impact on potential ground motions that would result from earthquake rupture of the Teton fault. Repeated episodes of faulting, erosion and deposition have resulted in a deep basin of late Cenozoic alluvial fill underlying northern Jackson Hole, including the Jackson Lake Dam area. In addition, episodes of glacial scouring and deposition in the immediate vicinity of the dam have created a shallow basin of largely unconsolidated late Quaternary alluvium. This geologic structure is characterized by observed large-scale lateral contrasts in seismic velocity, and localized zones of low near-surface seismic velocities. This structure serves to both amplify and prolong the duration of shaking at Jackson Lake Dam.

A 3D crustal velocity model is estimated using data from 1150 of the best located earthquakes recorded by Reclamation's seismic monitoring network (out of a total of 16,000 quakes recorded between August 1986, and May 2002). The horizontal resolution of the model is 5 km (3 mi). The

3D velocity inversion revealed a laterally extensive low-velocity region east of the Teton fault that includes Jackson Lake Dam. The low-velocity region extends to depths of ~4 km (2 mi) below the dam and exhibited the lowest velocities seen in the 3D P-wave velocity model (3.4 km/s).

The inverted 3D low-velocity basin velocity (LVB) model is refined by incorporating seismic refraction data (Behrendt et al., 1968; Byrd et al., 1994), and by modeling of microearthquake ground motions at the dam. Relatively strong velocity discontinuities between the LVB velocities and the surrounding high velocity medium are required to reproduce observed strong shear-wave arrivals that follow the direct shear-wave by 3-7 s in the weak ground motion data recorded at the dam. The LVB captures radiated seismic energy over a very wide cross section. Thus the basin is a very efficient seismic collector, and sites within the basin are likely to experience substantial multipathing for sources located beneath the basin (e.g., the Teton fault).

Based on 3D modeling, peak ground motions and Arias Intensities are likely to be largest in the western half of the LVB, return to levels comparable to those on the hanging wall near the fault (but outside of the LVB), and then decrease as one moves past the dam in the S15E direction. Peak motions at hard-rock sites within the LVB east of the dam are likely to be greater than those outside of the LVB, but adjacent to the fault. In contrast to sites within the western 8 km of the LVB, the dam is likely to be subjected to less extreme amplification from the combined effects of rupture directivity and LVB amplification. However, the modeled peak velocities and Arias Intensities at the dam are larger than those at sites located adjacent to the fault on the high-velocity portion of the hanging wall (outside of the LVB). These results indicate that the dam will be subjected to amplification both because of rupture directivity and as a result of being located within the LVB. The effect of rupture directivity is smaller at the dam for fault dips of 45° to 60°.

Site Response at Jackson Lake Dam

Weak-motion site response was measured at Jackson Lake Dam using an array of seven broad-band seismometers. Key observations are the presence of substantial long-period amplification and prolonged duration of shaking beyond some transition point located between stations 13+00 and 24+00; minimal long-period amplification at stations 12+00 and less (referenced to a bedrock site on the right abutment); and, high-frequency de-amplification on treated sections of the north embankment (referenced to a site just outside of the treated zone).

Strong ground motions at stations 13+00 and greater are expected to behave non-linearly. The observed weak-motion site response must be modified to account for non-linear soil behavior. The observed site response at station 24+00 is consistent with the 2D and 3D response of a shallow, low-velocity sedimentary basin, and likely results from the generation of surface waves, converted phases, and interface waves. 2D synthetic seismogram modeling of the site response data show that the extended ground motion durations observed at the surface are likely associated with a mixture of refracted S-waves, and horizontally propagating surface and interface waves. The 2D synthetic seismograms show that there is a critical distance range from the southern margin of the glacial scour, on which the concrete section of the dam is founded, where peak horizontal acceleration responses are likely to be amplified relative to most of the embankment section of the dam. These results indicate that 1D computer codes for modelling nonlinear soil behavior at the dam will need to be modified to account for 2D and 3D effects.

Ground Motion Modeling

Ground motion simulations of the Teton fault for multiple rupture scenarios were performed using kinematic rupture models of the fault, and propagation of seismic waveforms through the 3D model. A hybrid procedure was used to incorporate high frequencies and purely empirical Green's functions were also used to simulate ground motions to ascertain the sensitivity of ground motion estimates to source and propagation approximations. These simulations provided a range of possible ground motions, and provided constraints on parameters having the most significant effect.

The combined influences of rupture directivity and the LVB amplify rock input motions at the dam. The resulting motions are more like a soil site than a typical rock site. Based on ground motion simulations for the northern Teton fault (dips of 35° and 45°), the mean and 84th-percentile acceleration responses for periods > 0.35 s exceed empirical predictions for rock. For a fault dip of 35°, the mean and 84th-percentile acceleration responses exceed empirical predictions for soil on the south abutment for periods > 1 s. For a fault dip of 45°, the mean and 84thpercentile acceleration response exceed empirical predictions for soil on the south abutment for periods > ~1.5 s. Of particular note is that mean peak horizontal velocities exceed 90 cm/s for all dip scenarios. Hanging wall LVB amplification increases ground motions at Jackson Lake Dam in a way that is similar to the extreme ground motion effects of rupture directivity; In addition, the LVB produces extended duration of strong ground shaking at the dam, which is an effect that is not typically associated with rupture directivity.

Based on ground motion modelling and empirical site response data, ground motions at Jackson Lake Dam will have greater amplification, duration, and Arias Intensities than would be predicted using generic empirical ground motion attenuation relationships. We therefore recommend that the ground motions provided in this report be used directly for engineering analyses. However, if empirical relationships are used for engineering analyses, then magnitude proxies of the seismic loads should be **M** 8 for the rock ground motions, and **M** 9 for the soil ground motions. These recommended proxy magnitudes for soil sites are much larger than the moment magnitudes of all-segment and northern segment rupture scenarios of the Teton fault, but specifically account for the extended durations and amplifications of ground motions observed at the dam. The most likely scenarios for soil response and nonlinear soil calculations indicate rock ground motion durations of at least 80 seconds and soil durations possibly as long as 180 s for the embankment portion of the dam.

Ground motions are likely to vary substantially over the 1.5 km span of the dam, both along the dam's axis and in the upstream-downstream direction. That is because the low soil S-wave velocities result in wavelengths nearly equal to the dam's width at 1 Hz. In addition, the southern portion of the dam will shake less strongly and for shorter durations than the rest of the dam because it overlies more competent soils and rock. Consequently, the largest strains resulting from differential motions along the axis of the dam are likely to be located in the embankment section extending from stations 12+00 to 32+00.